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COAL GASIFICATION SYSTEMS
ENGINEERING AND ANALYSIS
FINAL REPORT
APPENDIX G - COMMERCIAL DESIGN AND TECHNOLOGY EVALUATION

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TABLE OF CONTENTS

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LIST OF TABLES

1.0 INTRODUCTION

This appendix contains a technology evaluation of five coal gasifier systems (Koppers-Totzek, Texaco, Babcock and Wilcox, Lurgi and BGC/Lurgi) and procedures and criteria for evaluating competitive commercial coal gasification designs. The technology evaluation is based upon the plant designs and cost estimates develoned by the BDM-Mittelhauser team.

2.0 STATE-OF-THE-ART OVERVIEW

Coal gasification involves adding oxygen and steam to coal, under controlled reaction conditions of temperature and pressure as well as flow, to form a raw gas composed of hydrogen, carbon monoxide, methane, carbon dioxide, nitrogen, ammonia, sulfur compounds and small amounts ov other components. The primary combustible fuel components of the raw gas are hydrogen and carbon monoxide along with lesser amounts of methane. The exact composition of the raw gas, in any specific case, is a function of many parameters, including:

- the feedstock coal composition
- the specific gasifier configuration and operating conditions
- whether the gasification utilizes pure oxygen or atmospheric air.

The raw gas may be further processed in various ways so as to obtain an end product of specific heating value and other characteristics.

2.1 History of Coal Gasification Technology

Coal gasifiers were used in Europe as early as the 1840's. By the early 1900's, there were 150 companies in Europe and the United States building gasifiers for fueling of kilns, furnaces and gas engines. In 1921, there were about 11,000 commercial gasifiers in the United States which consumed a total of more than 40,000 tons per day of coal. During the next decade,

the advent of natural gas and refined petroleum products led to a rapid decline of coal gasification in the United States. By 1948, there were only 2,000 gasifiers in use and today there is no significant, commercial use of coal gasification in the United States. However, there are a number of coal gasification technologies which have remained in successful commercial practice in other parts of the world for many decades.

The Lurgi coal gasifiers, developed in Germany, have been in use since the 1930's in over 18 different plants around the world. In South Africa alone, the SASOL complex contains three large Lurgi gasification plants including over eighty individual Lurgi gasifier reactors and processing over 90,000 tons per day of coal.* Other Lurgi plants have been operating in Germany, Scotland, England, Korea, India, Australia, Pakistan and Czechoslovakia for various periods of time.

The Koppers-Totzek (K-T) gasifiers, also developed in Germany, have been in worldwide commercial use since 1950 when the first commercial K-T gasifier was built in Finland. Nineteen plants including fifty-four individual gasifiers have been built or are now under construction in France, Finland, Japan, Spain, Greece, Turkey, India, South Africa, Thailand, Zambia and Brazil. The largest of these plants is now the one in South Africa.

The Winkler gasifier, another German development, has been in commercial use since 1926. Twenty-four Winkler plants have been built, including seventy individual gasifiers, in Germany, Japan, Czechoslovakia, Yugoslavia, Spain, India, Turkey and elsewhere.

Other gasifiers with commercial experience dating back many years include the Wellman-Galusha gasifiers, the Woodhall-Duckham/Gas Integrale gasifiers and the FW-Stoic gasifiers.

Over the past ten years, a great deal of technological development work has been underway in the United States as well as Europe to test and to demonstrate a host of more modern and more cost-efficient 'second generation' gasifiers.

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*The third Lurgi plant at SASOL is still under construction.

2.2 Characterization of Coal Gasification Processes

Table 2.2.1 presents a list of seventeen coal gasification processes ranging from those in commercial use to those in various stages of development, piloting and demonstration. The key design and operating parameters of pressure, temperature and gasifier bed configuration are also presented for each of the seventeen processes.

Table 2.2.2 is a rearrangement of Table 2.2.1 and characterizes the seventeen gasifiers according to their:

- bed configurations of fixed, fluidized or entrained beds with slagging or non-slagging bottoms
- levels of operating pressure
- levels of exit gas temperature.

It can be seen from these tables that gasifiers with slagging bottoms (those that discharge molten slag) operate with combustion zone temperatures of 2800°F or higher in order to melt the slag. Gasifiers with non-slagging bottoms (those that discharge solid ash) operate with combustion zone temperatures of below 2100°F so as not to melt the ash (slag). It can also be seen that the entrained bed gasifiers are: (a) slagging bottom gasifiers with high combustion zone temperatures and (b) generally operating at higher exit gas temperatures than are the fixed bed or the fluidized bed gasifiers. In general, gasifiers operating with higher combustion zone and higher exit gas temperatures are expected to yield lesser amounts, if any, of by-product tars, oils, naphtha and phenols. The yield of methane also appears to decrease with increasing gasifier temperatures.

The seventeen processes characterized in the tables are by no means an exhaustive list. There are a number of other processes under development in the United States, West Germany, Great Britain, Holland and Japan.

2.3 Major Gasification Projects Underway in the United States

For the purposes of this report, major gasification projects are arbitrarily defined as those that will gasify at least 1,000 tons per day of coal

TABLE 2.2.1. COAL GASIFICATION PROCESSES

	Gasifier Operating Conditions			Type of Gasifier		
	Pressure (psig)	Combustion Temperature (°F)	Gas Exit Temperature (°F)	Gasifier Bed	Gasifier Bottom	Number of Stages
IN COMMERCIAL USE:						
Lurgi	350-450	2000-2100	700-1200	Slowly moving	Non-slagging	One
Koppers-Totzek	10-15	3200-3600	2500-3000	Entrained	Slagging	One
Wellman-Galusha	10-15	2000-2100	1000-1200	Fixed	Non-slagging	One
Winkler	10-200	1700-2100	1600-2100	Fluidized	Non-slagging	One
W-D/Gas Integrale	0	1700-2100	1100-1300	Slowly moving	Non-slagging	Two
FW Stoic	0	1700-2100	1100-1300	Slowly moving	Non-slagging	Two
DEMONSTRATED:						
Lurgi/BGC	350-450	3200-3600	700-1200	Slowly moving	Slagging	One
Shell-Koppers	300-500	3200-3600	2500-2700	Entrained	Slagging	One
Texaco	500-2500	3000-3400	2300-2600	Entrained	Slagging	One
B & W	50-250	2800-3200	1700-1900	Entrained	Slagging	One
Saarburg/Otto	0-360	3000-4000	1500-1700	Entrained	Slagging	One
PILOTED:						
COGAS	25-75	3000-3600	800-900	Fluidized	Slagging	Six
IGT HYGAS	1000-1100	1800-1900	1200-1300	Fluidized	Non-slagging	Three
IGT U-GAS	10-350	1800-1950	1800-1950	Fluidized	Non-slagging	One
C-E, DOE, EPRI	0	3000-3400	1600-1800	Entrained	Slagging	Two
BuMines Synthane	600-1100	1300-1800	1200-1700	Fluidized	Non-slagging	One
IN DEVELOPMENT:						
BCR BIGAS	1000-1500	2800-3200	1600-1800	Entrained	Slagging	Two

Symbols and Abbreviations:

W-D	Woodall-Duckham Ltd.	COGAS	COGAS Development Company	BuMines	Bureau of Mines
FW	Foster Wheeler	IGT	Institute of Gas Technology		
BGC	British Gas Corporation	C-E	Combustion Engineering		
B & W	Babcock and Wilcox	DOE	U.S. Department of Energy		
BCR	Bituminous Coal Research	EPRI	Electric Power Research Institute		

TABLE 2.2.2. CHARACTERIZATION OF COAL GASIFICATION PROCESSES

	Type Of Bed					Pressure (psig)					Temperature (°F)		
	Fixed[a]	Fluidized	Entrained	Non-slagging[b]	Slagging[b]	0-25 Atmospheric	25-100 Low	100-350 Low Medium	350-600 Medium	600-2500 High	700-1600 Low	1600-2100 Medium	2100-3000 High
Wellman-Galusha	●			●		●					●		
W-D/Gas Integrale	●			●		●					●		
FW Stoic	●			●		●					●		
Lurgi	●			●					●		●		
Lurgi/BGC	●				●				●		●		
Winkler		●		●		●	●	●				●	
IGT U-GAS		●		●		●	●	●				●	
IGT HYGAS		●		●						●	●		
Bu Mines Synthane		●		●						●	●	●	
COGAS		●			●		●				●		
Koppers-Totzek			●		●	●							●
C-E, DOE, EPRI			●		●	●						●	
Saarburg/Otto			●		●	●	●	●				●	
B & W			●		●		●	●				●	
Shell-Koppers			●		●				●				●
BCR BIGAS			●		●					●		●	
Texaco			●		●					●			●

Notes:

[a] *Fixed and slowly moving beds*

[b] *Non-slagging beds have combustion zone temperatures below 2700 °F. Slagging beds have combustion zone temperatures above 2800 °F.*

to differentiate them from the so-called 'demonstration plants' that generally are a classification used for plants gasifying about 100 to 500 tons per day of coal.

Table 2.3.1 lists and briefly describes some of the major coal gasification projects currently underway in the United States. It is of interest to note that six of the eight projects will use gasifiers with slagging bottoms. It is also of interest that four of the eight projects will use high-temperature gasifiers with entrained beds.

There are two major constraints against the rapid building of a large-scale coal gasification industry in the United States. The most important constraint is the lack of investment capital. Many billions of dollars will be needed to open new coal mines and to build large gasification plants. The next most important constraint is that of obtaining state and Federal regulatory approvals for siting the plants, pricing of the end product gas and meeting environmental regulations. Another constraint that is of lesser severity, but one which becomes involved in regional and national politics and policy-making, is the obtaining of adequate water supplies for large gasification plants.

3.0 COMPARISONS OF THE FIVE GASIFIERS SELECTED FOR EVALUATION BY TVA

The BDM-Mittelhauser team has developed overall plant designs and cost estimates for each of the five coal gasification processes selected for evaluation of TVA. The results of those designs and cost estimates have previously been submitted in individual reports on each of the processes, and included:

- preliminary 'Facility Definition Designs'
- more extensive and detailed 'Facility Technical Designs'.

For the most part, the BDM-Mittelhauser designs were developed on the basis of modules, each gasifying 5,000 tons per day of coal. The cost estimates were then developed on the basis of four modules, including the appropriate spare equipment and general facilities, for gasifying a total of 20,000 tons per day of coal.

TABLE 2.3.1. SOME OF THE MAJOR COAL GASIFICATION PROJECTS UNDERWAY IN THE UNITED STATES

SNG USING LURGI GASIFIERS:	The Great Plains Coal Gasification project in North Dakota has been certified by the Federal Energy Regulatory Commission and has recently initiated actual construction. The project will use Lurgi fixed-bed, non-slagging gasifiers and convert about 13,000 tons per day of lignite into high Btu SNG.
MBG USING THE U-GAS GASIFIERS:	A municipal utility, Memphis Light, Gas and Water, has been awarded a contract by the Department of Energy (DOE) to design a plant using the U-GAS gasifiers to convert 3,000 tons per day of coal into MBG for industrial fuel. Design work is well underway if not completed.
SYNTHESIS GAS USING TEXACO GASIFIERS:	W.R. Grace & Company has been awarded a contract by the DOE to design a plant in Kentucky using the Texaco gasifiers to convert 2,000 tons per day of coal into synthesis gas for use as feedstock in ammonia production. Design work is well underway if not completed.
SNG USING LURGI/BGC GASIFIERS:	The Conoco project in Ohio has been selected for partial funding by the DOE in the design of a plant to convert 1,300 tons per day of coal into SNG using the Lurgi/BGC fixed-bed, slagging gasifiers. Design work is well underway.
SNG USING COGAS PROCESS:	The Illinois Coal Gasification Group (ICGG) project has been selected by the DOE for partial funding in the design of a plant to convert 2,300 tons per day of coal into SNG using the COGAS process. Design work is well underway. (This project is in competition with the Conoco project. The DOE plans to decide which of the two projects will merit continued funding through the construction and operation stages.)
ELECTRIC POWER USING TEXACO GASIFIERS:	Southern California Edison Company, Texaco and the Electric Power Research Institute (EPRI) are co-funding a project in California to convert 1,000 tons per day of coal into MBG using oxygen-blown Texaco gasifiers. The MBG will be used to fuel an integrated, electric power-generating gas turbine with an output of 100 megawatts. Final design is well underway.
MBG USING KOPPERS-TOTZEK GASIFIERS:	The Tennessee Valley Authority (TVA) plans to build a plant converting coal into MBG for fueling electric power-generating units. The initial unit will gasify 5,000 tons per day of coal. Ultimately, TVA plans four units for a total of 20,000 tons per day of coal gasification. TVA has evaluated Lurgi, Lurgi/BGC, Texaco, B&W and Koppers-Totzek gasifiers. The first unit will very probably use Koppers-Totzek gasifiers.
SYNTHESIS GAS USING TEXACO GASIFIERS:	Tennessee Eastman Company plans to build a large-scale plant using Texaco gasifiers for converting coal into synthesis gas for use as feedstock in petrochemical production. The coal conversion capacity has not been released.

3.1 Comparison of Design Characteristics

Table 3.1.1 presents the comparative design characteristics and parameters of the five gasification processes, based on one module for each process.

As shown in Table 3.1.1, the number of operating gasifiers required to gasify 5,000 tons per day of raw coal ranges from two, for the B&W and the BGC/Lurgi gasifiers, to eight for the K-T process. Thus, the capacity per gasifier ranges from 625 tons/day to 2,500 tons/day. Those capacities are not necessarily the maximum capabilities of the various gasifiers, but they probably approach the upper limit of their current capabilities.

It can be seen in Table 3.1.1 that the Lurgi and BGC/Lurgi gasifiers use considerably less oxygen than the other gasifiers. On the other hand, the Lurgi and the BGC/Lurgi gasifiers use much more steam than the others. It should also be noted that the slagging bottom BGC/Lurgi gasifier does not use as much steam as the non-slagging bottom Lurgi gasifier since the slagging gasifier does not require excess steam in order to maintain a low combustion zone temperature.

The Lurgi and BGC/Lurgi gasifiers have slowly descending, fixed beds. The B&W, the K-T and the Texaco gasifiers all have entrained beds and consequently operate at much higher raw gas exit temperatures.

The gasifier operating pressure levels range from 20 psia for the K-T process to 690 psia for the Texaco process.

In terms of their impact on plant costs and other factors, the relative effect of each of the design characteristics may be summarized as:

- <u>Gasifier coal capacity</u>: Higher coal capacities per gasifier reduce the number of gasifiers required, along with all of their related equipment and controls, and therefore reduce the overall plant costs.
- <u>Oxygen consumption</u>: Higher Oxygen consumptions require larger air separation units (to provide the oxygen) and therefore increase the overall plant costs.
- <u>Steam usages</u>: Higher steam usage increases overall plant costs and results in more effluent waste water (contaminated process steam condensate) requiring more effluent water treatment and reuse or disposal.

TABLE 3.1.1. COMPARATIVE DESIGN CHARACTERISTICS OF TVA GASIFICATION MODULES

	B & W	K-T	TEXACO	LURGI	BGC/LURGI
OPERATING GASIFIERS	2	8	3	6	2
SPARE GASIFIERS	1	1	1	1	1
FEEDSTOCK COAL:					
Raw coal feed to module, T/D [a]	5,000	5,000	5,000	5,000	5,000
Dried coal feed to gasifiers:					
As is (dried coal), T/D	4,614	4,567	5,000 [b]	5,000 [b]	5,000 [b]
As MAF coal, T/D	3,806	3,806	3,806	3,806	3,806
Raw coal/operating gasifier, T/D	2,500	625	1,667	833	2,500
OXYGEN (as 100 % O_2):					
T/D per module	3,779	4,033	4,188	2,061	2,031
lbs/lb of MAF coal to gasifers	0.99	1.06	1.10	0.54	0.53
GASIFICATION STEAM:					
T/D per module	392	678	401 [c]	9,775	1,317
lbs/lb of MAF coal to gasifiers	0.10	0.18	0.12	2.57	0.35
lbs/lb of 100 % O_2	0.10	0.17	0.11	4.74	0.65
RAW GAS PRESSURE, psia	240	20	690	450	450
RAW GAS TEMPERATURE , °F	1,800	2,700 [d]	2,500	950	610
COMBUSTION ZONE TEMPERATURE, °F	3,000	3,300	3,000 [e]	1,900	3,000 [e]

NOTES:

[a] Short tons (2,000 pounds) per day.

[b] Coal drying not required.

[c] Coal slurry water chemically converted during gasification.

[d] Before quenching for slag solidifcation. Entry to waste heat boiler, after quenching, is about 1,800 °F.

[e] Estimate, after allowance for heat loss and endothermic reactions.

- Gasification pressure: Higher gasification pressure reduces the compression requirements of the end product gas. However, higher gasifier pressures require higher pressure steam, more compression of the oxygen feed, and more costly coal feeding equipment. It is very difficult to generalize the overall cost impact of higher gasifier pressures, but it probably lowers plant costs.
- Type of bed: The fixed-bed gasifiers (Lurgi and BGC/Lurgi) have a high inventory of coal in their beds which provides an inherent safety factor in the event of a coal feed failure while oxygen feed continues to enter the gasifier. The bed's coal inventory provides time to correct the coal feed failure or to shut off the oxygen feed so as to avoid a runaway temperature rise in the gasifiers. The entrained-bed gasifiers do not provide this inherent safety factor.

  However, the fixed-bed gasifiers require the coal feed to be sized within a specific range so as to avoid gas channeling in the beds resulting from plugging of the spaces between coal particles by coal fines. In other words, the coal must be crushed and graded and the fines must be rejected. Depending upon the coal's friability, the rejected fines may constitute as much as 25 percent of the raw coal. Some of the fines may be burned to produce steam in the plant's auxiliary boilers, and some of the fines may have to be sold.

  The entrained-bed gasifiers operate at much higher temperatures than the fixed-bed gasifiers, and will therefore produce very little, if any, tars, oils, naphtha or phenols. The separation and recovery of tars, oil and naphtha as liquid fuels is feasible but increases plant costs and the waste water contamination levels. The same is also true for the separation and recovery of phenols as a salable by-product. Thus, from the environmental control viewpoint, the entrained-bed gasifiers are advantageous relative to the fixed-bed gasifiers.

3.2 Comparison of Yield and Performance Characteristics

Table 3.2.1 presents the comparative yields and other performance characteristics of the five gasification processes, based on one module per process. The Lurgi and the BGC/Lurgi data in the table reflect a preliminary 'Facility Definition Design' only, whereas the three processes in the table reflect a detailed 'Facility Technical Design'. Therefore, the Lurgi and the BGC/Lurgi data may not be completely comparable to the other three processes.

The yields of methane (CH_4) and the tar-oil-naphtha in Table 3.2.1 reflect the previous observation herein that high-temperature, entrained-bed gasifiers should produce little methane and essentially no tar-oil-naphtha. It should also be noted that the fixed-bed BGC/Lurgi gasifier produces less methane than the fixed-bed Lurgi gasifier, which reflects the higher combustion zone temperature of the slagging BGC/Lurgi gasifier relative to the non-slagging Lurgi gasifier.

The Lurgi and the BGC/Lurgi plants use considerably more steam (see Table 3.1.1) than the other three plants and therefore produce more contaminated waste water. The ammonia recovery from the Lurgi and the BGC/Lurgi plants is a by-product of the need to treat and upgrade their waste waters for reuse in-plant as cooling water makeup.

The Lurgi and BGC/Lurgi gasifiers require a crushed and size-graded coal feed containing no coal fines. A part of the coal fines produced by crushing the raw coal is burned as boiler plant fuel (Table 3.2.1), and the remainder of the coal fines would have be sold (Table 3.2.2) as a by-product. The tar-oil-naphtha by-products are also burned as boiler plant fuel.

Of the three entrained-bed gasifiers (B&W, K-T and Texaco), the K-T gasifier exhibits the lowest coal carbon conversion in Table 3.2.1. The B&W design recovers and recycles most of the unburnt carbon (char) carried out of the gasifier with the raw gas. The Texaco process recovers most of the unburnt carbon (soot) carried out of the gasifier with the raw gas and recycles the recovered soot-water stream for reuse in the gasifier coal feed slurrying.

TABLE 3.2.1. COMPARATIVE YIELD AND PERFORMANCE CHARACTERISTICS OF TVA GASIFICATION MODULES

	B & W	K-T	TEXACO	LURGI	BGC/LURGI
PERCENTAGE OF COAL CARBON CONVERTED	97.46	95.00	98.98	99.02	99.52
PERCENTAGE OF COAL CARBON CONVERTED TO CH_4	0.00	0.59	0.73	13.55	10.86
T-O-N YIELD, wt % on MAF coal [a]	0.00	0.00	0.00	8.09	8.09
ENDPRODUCT MBG:					
Higher heating value, Btu/SCF	303	305	291	308	380
Gross MBG product, 10^6 SCF/D	275.0	249.4	271.1	289.5	239.0
Gross MBG product, 10^9 Btu/D	83.3	76.0	78.9	89.2	90.8
Net MBG product, 10^6 SCF/D	244.4	230.6	269.4	289.5	239.0
Net MBG product, 10^9 Btu/D	74.0	70.3	78.4	89.2	90.8
BYPRODUCT SULFUR, T/D [b]	185	183	184	177	179
BYPRODUCT AMMONIA, T/D	0	0	0	67	67
INPLANT FUEL USAGE:					
MBG, 10^6 SCF/D	30.6	18.8	1.7	0.0	0.0
T-O-N, T/D	0.0	0.0	0.0	308.0	306.0
Coal, T/D	0.0	0.0	0.0	996.0	313.0
Total fuel, 10^9 Btu/D	9.3	5.7	0.5	32.4 [c]	17.4 [c]
RAW WATER DEMAND, gpm:					
Boiler feedwater makeup	114	141	22	1400	105
Cooling water makeup	2848	1374	2056	585 [d]	205 [e]
Other users	-	-	77	115	105
Water treatment makeup (at 5 %)	148	76	108	105	20
Contingency (at 10 %)	310	159	227	220	45
Total raw water demand	3420	1750	2490	2425	480

NOTES:

[a] T-O-N is tar, oil and naphtha.

[b] Short tons (2,000 pounds) per day.

[c] Coal taken as 11,000 Btu/lb (HHV) and T-O-N taken as 17,000 Btu/lb (HHV).

[d] 1310 gpm of treated wastewater also used as cooling water makeup.

[e] 205 gpm of treated wastewater also used as cooling water makeup.

TABLE 3.2.2. COMPARATIVE COST FACTORS OF TVA GASIFICATION PLANTS

	B & W	F-T	TEXACO	LURGI [a]	BGC/LURGI [a]
COAL GASIFIED, T/D	20,000	20,000	20,000	20,000	20,000
BOILER COAL, T/D	0	0	0	3,984	1,252
COAL FINES SOLD, T/D	0	0	0	6,456	9,188
TOTAL COAL FEED, T/D	20,000	20,000	20,000	30,440	30,440
TOTAL CAPITAL REQUIRED, MM $	3,347	2,371	2,091	2,747	2,061
O & M COSTS, MM $/YEAR	138	188	128	93	35
COAL, CATALYSTS & CHEMICALS, MM $/YEAR	181	181	181	274	274
TOTAL OPERATING COSTS, MM $/YEAR	319	369	309	367	309

NOTE: All cost factors are in 1980 dollars.

[a] These two cost estimates reflect a lower level-of-effort design and may not be completely comparative to the other three cost estimates.

Thus, the B&W and the Texaco designs achieve a multi-pass coal carbon conversion. The K-T design does not recover and recycle unburnt carbon carried out of the gasifier with the raw gas, which probably explains why the K-T process exhibits the lowest coal carbon conversion.

3.3 Comparison of Cost Factors

Table 3.2.2 presents the capital investment and the annual operating cost estimates for the five gasification processes.

As discussed above, the Lurgi and the BGC/Lurgi designs reflect a lower level-of-effort and may not be completely comparable to the other three cost estimates.

Of the three entrained-bed gasification processes, the Texaco plant exhibits the lowest estimated capital cost as well as the lowest estimated operating cost in Table 3.2.2.

The levelized life-cycle product prices and the detailed cost estimating methodology are presented and discussed in Appendix D.

4.0 COMPARATIVE EVALUATION CRITERIA

This section covers the criteria for validating and comparing A/E conceptual designs.

Risk management is a major element of these comparison criteria, especially in the areas of development, schedule and plant operability. The evaluation and analysis of risk in most cases is very subjective and varies from client to client. A project team should identify the risks in each A/E conceptual design based on the criteria discussed in the following sections. Generally, the systems should be graded as acceptable or unacceptable based on the team's engineering judgment.

4.1 Validation

Since design comparison is meaningless if the design is not correct, criteria have been established for validation of A/E conceptual designs. Prominent on the list of validation criteria are design data base, design and cost correctness, design feasibility, and compatibility of the design with the Integrated Facility Requirements. The design and cost drivers identified in Appendix A, the cost data and methodologies in Appendix D and the issues raised in the Critical Technology Assessments in Appendix F are essential in validating the designs.

4.1.1 Design Data Base

Each A/E conceptual design should be reviewed to determine whether the design base experimental data are acceptable. The project team should measure the effectiveness of these criteria on whether good data from long, stable pilot runs are well documented by the A/E. Since this evaluation will be rather subjective, the project team must review each case and rate them as having a good, acceptable or poor data base. Specific items to be reviewed are the degree to which the commercial unit must be scaled-up from experimental or demonstration size and performance on similar coal, gases, etc.

4.1.2 Energy and Material Balance

The A/E conceptual designs need to be checked to ensure each system mass-balance is within one pound per hour on both compounds and elements. Additionally, system energy balances should be checked for agreement to within 1%. Computer simulations should be used as appropriate to check energy and material balances.

Where some systems or subsystems fail to satisfy these validation criteria, the team's estimates of the changes that would be required to validate

each should be used for the comparison step. If it is judged, in the project team's experience, that failure to satisfy these criteria does not affect the system capital and/or operating requirements, no revisions or changes should be made.

Upon confirmation of the energy and material balances, the A/E cost data should be validated using the costing and product pricing methodologies from Appendix D.

4.1.3 System Technical Feasibility

The technical feasibility of A/E conceptual designs should be evaluated as to whether the proper equipment has been selected and whether critical items have been spared. Each design should be reviewed to determine whether the system utilizes proven equipment in a configuration and/or service similar to those previously used successfully in the same or similar scale.

Each system should be reviewed as to whether the issues raised in the Critical Technology Assessment (Appendix F) are successfully addressed in sufficient detail. Issues such as materials reliability and approaches to resolution will be of predominate interest. Each critical technology assessment discussion should be rated as acceptable or unacceptable.

4.1.4 Compliance with Scope of Work and Integrated Facility Requirements Document

Each A/E conceptual design should be reviewed for compliance with the scope of work. A qualitative estimate of the impact of each deviation from the Scope of Work should be made. Additionally, the A/E design quantities, such as product quality, should be reviewed for agreement with corresponding Integrated Facility Requirements Document quantities. Agreement within 10% is desirable. Those requirements exceeding this limit should be investigated for correctness and/or unusual circumstances resulting in the deviation.

5.0 COMPARISON AND EVALUATION

Comparison and evaluation follow the validation effort. Here the valid systems and facilities in the A/E designs are compared, both with other A/E designs and with the Reference Facility Designs of Appendix B, for facilities employing the same gasification technology.

5.1 Comparison

System technical and cost comparison data should be tabulated on Tables 5.1.1 and 5.1.2, respectively. Following system data tabulation, overall facility technical and cost comparison data should be listed on Tables 5.1.3 and 5.1.4. Where some systems or subsystems failed to satisfy the validation criteria, overall designs should be compared using the project team's estimates of the changes that would be required to validate each system or subsystem.

5.2 Evaluation

The A/E design data compiled in Tables 5.1.1 through 5.1.4 should next be evaluated. Evaluation criteria for each design are shown in Table 5.2.1 and discussed below.

5.2.1 System Performance and Reliability

Each system should be compared for complexity. Generally, those systems having fewer unit operations are more reliable; however, this cannot be used unilaterally. Additional comparison criteria must include technology maturity scale-up requirements, critical technology assessment, and redundancy of high-risk components.

Each system should be reviewed for its ability to process alternate coals. Additionally, each system needs to be reviewed for startup and shutdown considerations as well as turndown operation flexibility. Each system should be reviewed to ensure the scale is appropriate to modular implementation.

TABLE 5.1.1. SYSTEM TECHNICAL COMPARISON

GASIFICATION TECHNOLOGY: ______________

SYSTEM: ______________

ITEM		DESIGN A	DESIGN B	REF. FACILITY
Licensor, Vendor, or Type				
No. of Trains/Module				
Process Stream Flow Rates				
Stream Description	Flow Units			
By-Product Flow Rates				
Stream Description	Flow Units			
Catalyst and Chemicals				
Description	Flow Units			
Emissions				
Stream Description	Flow Units			
Operating Labor, man-hours/yr				
Supervision, man-hours/yr				
Land Required, acres				

TABLE 5.1.1. SYSTEM TECHNICAL COMPARISON (continued)

GASIFICATION TECHNOLOGY: ____________

SYSTEM: ____________

ITEM	DESIGN A	DESIGN B	REF. FACILITY
Utilities			
Steam Required, psig/°F			
, lb/hr			
, psig/°F			
, lb/hr			
Steam Produced, psig/°F			
, lb/hr			
, psig/°F			
, lb/hr			
Cooling Water , T °F			
, gpm			
Power, kWh/h			
Plant Air, SCFH			
Nitrogen, SCFH			
BFW, psig/gpm			
Other Water, psig/gpm			
Fuel Gas, MM Btu/Hr			
Others			

TABLE 5.1.2. SYSTEM COST COMPARISON

GASIFICATION TECHNOLOGY: ______________

SYSTEM: ______________

ITEM	DESIGN A	DESIGN B
Capital Costs, $		
Total System Capital Cost		
Operating Costs, $/Yr		
Catalyst and chemicals		
Description		
Electric Power		
Operating Labor		
Supervision		

TABLE 5.1.3. PLANT TECHNICAL COMPARISON

GASIFICATION TECHNOLOGY: ______________

ITEM	DESIGN A	DESIGN B	REF. FACILITY
Coal			
Delivered, TPD			
Exported, TPD			
Net, TPD			
, MM Btu/day			
Medium-Btu Gas			
Gross Production, MM SCFD			
Internal Consumption, MM SCFD			
Net MBG Produced, MM SCFD			
MBG HHV, Btu/SCG			
Net MBG Production, MM Btu/day			
Power			
Import Electric Power, kWh/day			
(at 3413 Btu/kWh) , MM Btu/day			
Chemical and Catalyst Imports			
Miscellaneous Energy Imports and Exports (Fuels and energy streams only)			
By-Product Export			
Ammonia, ST/D			
Sulfur, LT/D			
Overall Thermal Efficiency, %*			

$$\text{*Overall Thermal Efficiency} = \frac{\text{Net MBG HHV + Misc. Export Fuels}}{\text{Net Coal HHV + Import Electric Power + Misc. Imports}} \times 100.$$

TABLE 5.1.4. PLANT COST COMPARISON

GASIFICATION TECHNOLOGY: ____________

ITEM	DESIGN A	DESIGN B	REF. FACILITY
Capital Costs			
Total System Capital Investment			
Project Contingency			
Owners Cost, Engineering, General and Administrative			
Contractor's Fee	______	______	______
Total Facility Investment			
Paid-up Royalties			
Startup and Testing			
Allowance for Funds Used During Construction	______	______	______
Total of Other Capitalized Costs			
Initial Charge of Catalyst and Chemicals			
Materials Inventories			
Spare Parts Inventories			
Minimum Cash Balance	______	______	______
Total Working Capital			
Land			
Total Capital Requirements			

TABLE 5.1.4. PLANT COST COMPARISON (continued)

GASIFICATION TECHNOLOGY: ______________

ITEM	DESIGN A	DESIGN B	REF. FACILITY
Operating Costs			
Raw Materials (Coal)			
Catalyst and Chemical Makeup			
Electric Power			
Operating Supplies			
Maintenance Labor			
Maintenance Supplies			
Supervision			
General Plant Staff			
Administrative & General Overhead			
Property Taxes & Insurance			
Gross Annual Operating Cost			
By-Product Credits			
Net Annual Operating Cost			
Total Uniform Annual Equivalent Revenue Reqmt.			
Annual Net MBG Production, MM Btu			
Uniform Annual Equivalent Product Cost, $/MM Btu			

TABLE 5.2.1. EVALUATION CRITERIA

I. SYSTEM PERFORMANCE AND RELIABILITY

A. Maturity of technology
B. Scale-up requirements
C. Complexity
D. Critical technology assessment
E. Operating requirements
F. Flexibility
G. Redundancy

II. SYSTEM COST COMPARISON

A. Total system capital requirements
B. System operating costs

III. PLANT PERFORMANCE

A. Gross coal requirement
B. Net coal requirement
C. Net MBG produced
D. Imported electric power
E. By-products exported
F. Catalyst and chemical consumption
G. Miscellaneous exports and imports
H. Flexibility

IV. PLANT DESIGN RELIABILITY

A. Maturity of technology
B. Complexity
C. Redundancy of high-risk components
D. Critical technology assessment

V. PLANT COST

A. Total capital requirements
B. Net annual operating cost
C. Uniform annual equivalent product cost

VI ENVIRONMENTAL RELATED CRITERIA

A. Maturity of control technology
B. Effluents pose siting limits
C. By-products pose environmental hazards

5.2.2 System Cost Comparison

Total system capital requirements and annual operating costs should be compared. This comparison needs to be balanced against the system performance and reliability comparison for eventual selection of the recommended system to be installed.

5.2.3 Plant Performance

After evaluation of the individual systems is complete, the overall plant or facility performance should be evaluated to determine the difference in operating performance of the A/E designs. This evaluation should consider all of the imports and exports associated with the facility in order to determine the impacts on the transportation and commodity markets.

5.2.4 Plant Design Reliability

On a plant basis, the integrated facility design reliability should be evaluated as was done on a system basis (see 5.2.1).

5.2.5 Plant Cost

The validated facility costs should be compared to determine the most economical process or processes. The product costs need to be compared to the overall thermal efficiency in order to evaluate the benefits of different heat integration schemes.

5.2.6 Environmental Related Criteria

The environmental residuals need to be evaluated to determine their impact on the surroundings. The maturity of the control technology is of utmost importance in determining the reliability of the system to produce an innocuous effluent.